Automated Profiling of the Troposphere

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A system operating at radio wavelengths, which continuously profiles the winds, temperature, and humidity of the troposphere, is discussed. Fixed-beam Doppler radar is used for measurement of the winds and tropopause height; millimeter-wave radiometry with antenna beams fixed-pointed to the zenith is used for temperature, humidity, and liquid measurements. The system operates unattended during almost all weather conditions; typical examples of data are presented.

Introduction

PRELIMINARY measurements of vertical profiles of meteorological parameters in the troposphere using ground-based, radio-wavelength remote sensing instruments were presented at the First International Conference on the Aviation Weather System in Montreal.[1] In this paper we present a progress report on the development of the Profiler system and present data that illustrate the continuous monitoring of atmospheric variables.

The Profiler is being developed by the Wave Propagation Laboratory (WPL) and the Prototype Regional Observing and Forecasting Service (PROFS) of NOAA's Environmental Research Laboratories (ERL). The data will be used by PROFS to test improved mesoscale forecasting methods. It is clear that other potential uses of such a device include furnishing synoptic scale data now obtained by balloon soundings, complementing data obtained with satellite sounders, and supplying data to commercial aviation for fuel-efficient flight planning.

The Profiler uses a combination of active (radar) and passive (radiometer) devices (Fig. 1) operating at radio wavelengths so that data can be obtained in nearly all weather conditions. Data from the various remote sensors and from conventional surface instruments are brought together in a central computer that generates the profiles from data measured for a specified averaging time. The goal is to develop an instrument that will produce continuous profiles with unattended operation and will also be simple enough for operational meteorology. The system shown in Fig. 1 represents a significant step in achieving these goals. It produces continuous profiles (currently updated every 20 min) automatically with unattended operation. The only moving parts are in the surface anemometer and in the data recording and display printouts. The accuracy and limitations of this system are being explored and improvements and simplifications are being made so that its use will be attractive for operational meteorology as well as for research.

Except for the vhf radar, the system shown in Fig. 1 is located at the Weather Service Forecast Office at Stapleton International Airport, Denver, Colorado. The vhf radar is located at Platteville, Colorado, about 45 km northeast of Denver, and its data are transmitted to the central computer by telephone. Two radars capable of measuring winds in the optically clear air as well as in precipitation are being evaluated for wind profiling. The uhf radar is just being completed. The two millimeter-wave radiometers have a total of six channels; their data are used with the surface data to calculate profiles of temperature and humidity and the total water vapor and liquid in a vertical column of air. Other meteorological quantities such as pressure heights are also derived. Partial Profiler data are transmitted to Boulder, Colorado, every 20 min to allow continuous monitoring of system performance. Detailed data are sent to PROFS for use by meteorologists.

Wind Profiles

The vhf radar was developed by the Aeronomy Laboratory of ERL. It operates at a 6-m wavelength and uses a large (100 × 100 m), but low-cost antenna. Its height resolution and minimum attainable height are relatively large because of bandwidth limitations imposed by frequency authorizations. This radar has been operating for about a year. Verification of the accuracy of remotely measured wind profiles is not an easy task. As reported previously,[1] there is reasonable agreement with winds measured by balloon soundings made at Denver; however, these comparisons are not sufficient to verify the radar data because of the large spatial separation of the instruments, particularly at upper levels where the balloon has been transported far from the launch site. Attempts to compare the winds measured by radar with winds measured by instrumented aircraft were also unsatisfactory. The best comparisons to date were made by colocating a microwave Doppler radar next to the 6-m radar and pointing at the same elevation angle. The microwave radar provides an extremely accurate horizontal wind profile, but it can operate only when precipitation targets are present. Figures 2 and 3 illustrate the wind profile comparisons for the orthogonal wind components measured with the two radars. These data were obtained during a spring snowstorm; the 3-cm radar measured the wind using snow particles as a wind tracer, while the 6-m radar measured the wind using backscatter from turbulent eddies of the atmosphere. As shown in the figures, the microwave radar has much better height resolution and lower minimum height coverage. (The microwave data illustrate the resolution expected of the uhf radar, but the uhf radar should be able to measure wind profiles in clear and cloudy weather as well as during precipitation.) Some of the wind profiles measured by the 3-cm radar showed very large gradients in height and time. In these cases the 6-m radar measured wind profiles similar to those shown because of the filtering effects of its coarse height resolution. These comparisons indicate that the 6-m radar is operating approximately as expected, but additional data are needed to specify the accuracy of the system.

Continuous wind profiles provided by the 6-m radar during a frontal passage are shown in Fig. 4. In the upper levels there is insufficient signal strength to obtain a measurement; the

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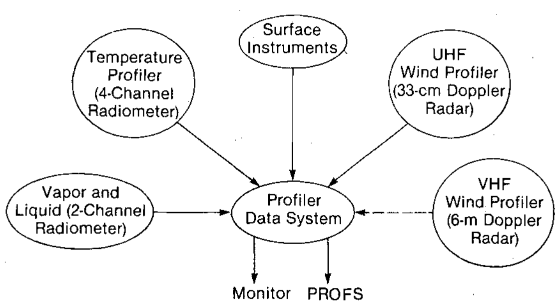

Fig. 1 Components of the Profiler system.

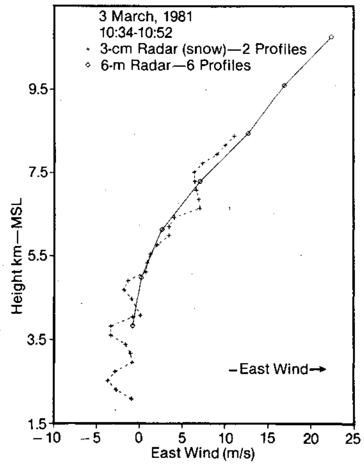

Fig. 2 Comparison of the east wind measured at Platteville, Colorado, by microwave (3-cm) radar using snow particles as wind tracers and by vhf (6-m) radar using refractivity fluctuations as wind tracers. Local height is 1.5 km MSL.

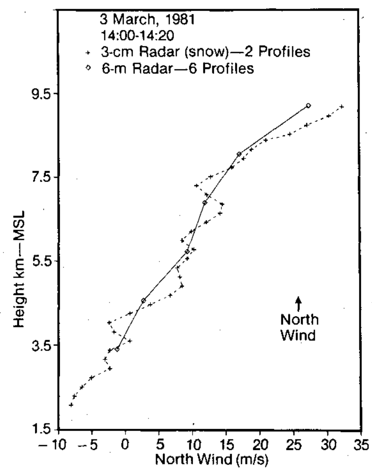

Fig. 3 Comparison of the north wind measurements as in Fig. 2.

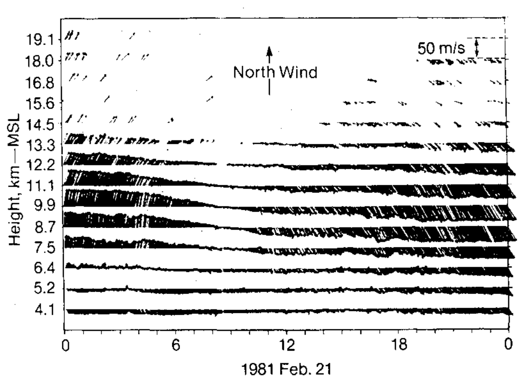

Fig. 4 Horizontal winds measured at Platteville, Colorado, by vhf (6-m) radar during a frontal passage. Profiles are computed automatically using an algorithm to eliminate data contaminated by aircraft interference.

raw data are rejected on the basis of poor signal-to-noise ratio. In the lower levels the data are examined for temporal continuity to reject interference from aircraft. It should be noted that these data were acquired with an average transmitted power of only 100 W; future plans call for a transmitter with 1 kW average power so that, in a case such as the one shown, wind profiles could be acquired to about 20-km altitude (MSL). The maximum altitude is expected to be somewhat lower during summer months.

The 6-m radar also provides vertical air motions, as illustrated in Fig. 5. Note that at the start of the record the vertical velocities are very small (<0.1 m/s) at all heights. Vertical winds are measured to greater heights (20 km MSL in this case) than horizontal winds because at 6-m wavelengths a partial specular reflection from stable layers in the atmosphere is observed with a zenith-pointing antenna. The quiet periods in the record therefore indicate the precision of vertical motion measurements. The very active periods appear to be driven by synoptic activity; the gravity wave motion apparent in Fig. 5 is probably caused by the zonal winds over the continental divide.[2] At present, the primary use of the data obtained from the vertically pointing antenna is to measure the height of the tropopause,[3] but direct measurement of vertical motions with temporal averaging to remove wave effects may prove valuable in mesoscale forecasting.

The uhf radar (33-cm wavelength) is nearing completion. Preliminary tests indicate that it will provide wind measurements with good height resolution (100-200 m) in the boundary layer and provide data to 5- to 10-km altitude with 300- to 600-m height resolution.

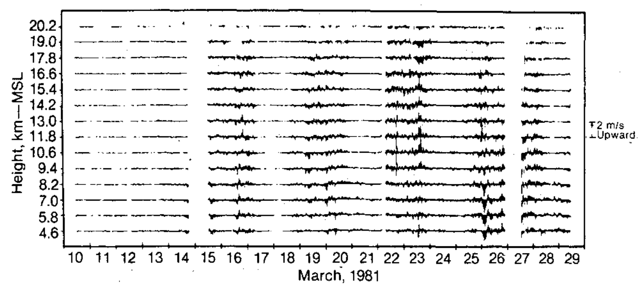

Fig. 5 Vertical winds measured at Platteville, Colorado, by vhf (6-m) radar, March 10-29, 1981. Record gaps are caused by failure to change tapes. Data shown are actual measured velocities; record is blank if the signal-to-noise ratio did not exceed threshold.

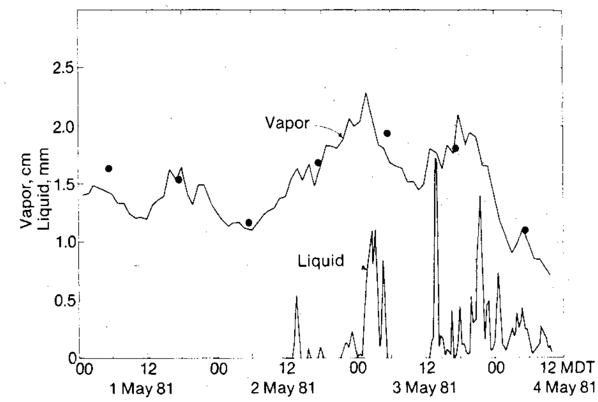

Fig. 6 Continuous precipitable water vapor and total liquid measured with a dual channel (1.45- and 0.95-cm) radiometer. Corresponding radiosonde point measurements for water vapor, obtained twice daily, are shown as dots. The radiosondes do not measure liquid.

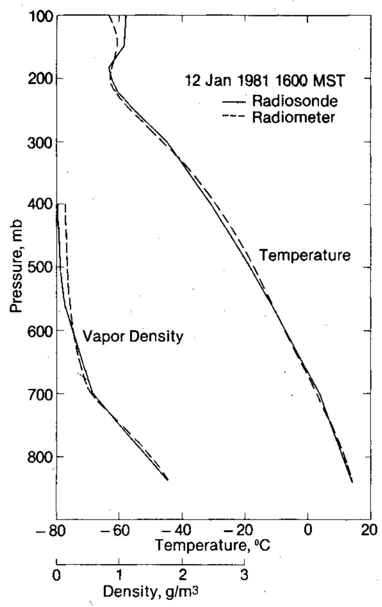

Fig. 7 Comparison of temperature and water vapor profiles measured by radiometry and radiosonde.

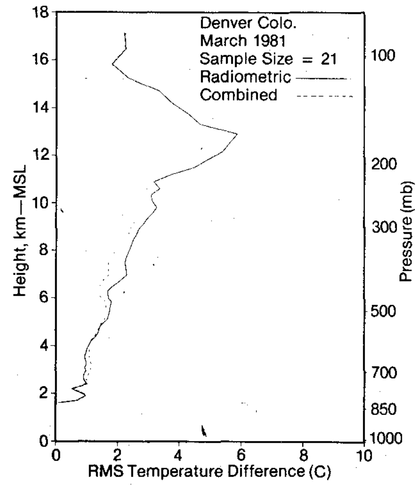

Fig. 9 Root mean square temperature difference of radiometrically measured temperature profiles and radiosonde profiles with and without radar-measured tropopause height.

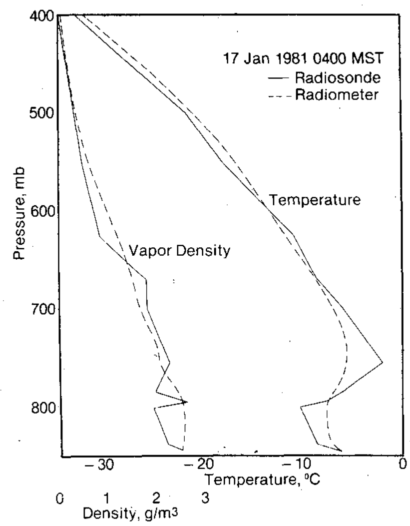

Fig. 8 Comparison of temperature and water vapor profiles as in Fig. 7, but for more complex profile structure.

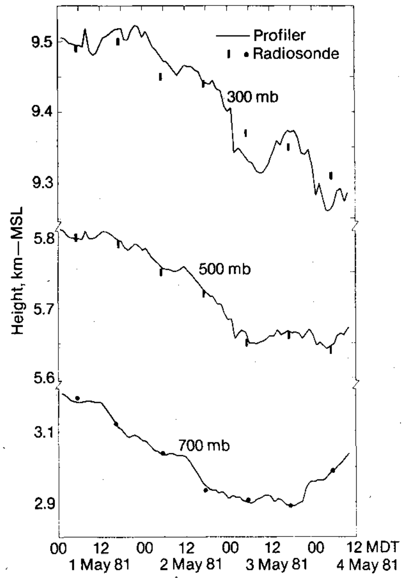

Fig. 10 Continuous pressure heights measured radiometrically and corresponding radiosonde points.

Precipitable Water Vapor and Integrated Liquid

The dual-channel radiometer that measures the total water vapor and liquid in a vertical column of the atmosphere has been in operation at Stapleton Airport for nearly a year. These radiometer channels operate at 1.45- and 0.95-cm wavelengths. Long-term comparisons of the radiometric data with radiosondes have proved the accuracy of this instrument.[4] Figure 6 illustrates the continuous data provided by this instrument and shows comparisons with radiosonde data for a period that included liquid-bearing clouds and rain. (Note that the radio-wavelength radiometers operate in clouds and rain, whereas infrared devices are unable to do so.) These data have been of interest to short-term forecasters. When temperature information is included, the radiometers can detect the presence of super-cooled liquid and the resulting icing of aircraft.[5]

Temperature/Humidity Profiles

The Profiler system uses a four-channel millimeter-wave radiometer (wavelength about 5.5 mm) as its primary tool for measuring temperature profiles. When data from the four-channel and dual-channel radiometers are combined with surface data, we obtain both temperature and humidity profiles. The humidity profiles are not as accurate as the temperature profiles because the radiometric wavelengths used are not well suited for profiling humidity.

An example of radiometrically measured profiles is shown in Fig. 7. The agreement with the radiosonde profile is very good for this simple case. A comparison for a more complex case (Fig. 8) shows that the radiometric profile follows the trend of the radiosonde profile, but its limited height resolution is apparent. If additional information such as the height of an elevated inversion or the height of the tropopause can be obtained by a zenith-pointing radar, then the radiometric profile can be refined. This is illustrated in Fig. 9, where a marked improvement of the profiles near the tropopause is seen when the radar-measured tropopause height (from 12- to 14-km altitude for this data set) is used with the radiometric data. Note also that the improvement extends well below the tropopause.

If radiometric measurements are used to derive integrated measurements, then (analogous to the dual-channel measurement of total water vapor and liquid) the data are in excellent agreement with radiosonde data. This is illustrated in Fig. 10, where the height of the 300-, 500-, and 700-mb pressure surfaces are shown for four days and compared with the radiosonde measurements. The heights of isotherms are likewise found to be in excellent agreement with radiosonde data.[1]

Future Expectations

Refinements in data processing and instrumentation will continue for quite some time before we will have a device ready for operational meteorology. Moreover, full utilization of the continuous data sets by meteorologists will require development of new models and forecasting methods. We expect to supply routinely in 1982 continuous profile data, albeit not perfect, so that meteorologists can begin the process of understanding and utilizing these new data sets.

We are currently constructing three additional vhf radar wind profilers located near Sterling, Craig, and Durango, Colorado, from 150 to 300 km from Denver. Data from these sites should enable PROFS to develop better short-term forecasts because significant weather systems approach Denver from these locations. Data from these sites will be transmitted by telephone to the Profiler computer in Denver.

Acknowledgments

The Platteville radar is operated jointly by the Wave Propagation Laboratory and the Aeronomy Laboratory of NOAA's Environmental Research Laboratories. This radar was originally developed by the Aeronomy Laboratory. The Profiler system is being developed by a team of workers, and the authors gratefully acknowledge the contributions from the many team members.

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